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Lichtsuchende: exploring the emergence of a cybernetic society

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Abstract. In this paper, we describe *Lichtsuchende*, an interactive installation, built using a society of biologically inspired, cybernetic creatures who exchange light as a source of energy and a means of communication. Visitors are invited to engage with the installation using torches to influence and interact with the phototropic robots. As well as describing the finished piece, we explore some of the issues around creating works based on biologically inspired robots. We present an account of the development of the creatures in order to highlight the gulfs between conceptual ideas of how to allow emergent behaviours and the manners in which they are implemented. We also expose the interrelations and tensions between the needs of the creatures as they emerge and the needs of the creators, to understand the duet between the cyber-organisms and their initiators. Finally, we look at the ways in which creators, robots and visitors are enrolled to perform their functions, so that the network of activity can be woven between all parties.

1 Introduction

In this paper, we are concerned with systems inspired by biology (and to some extent evolution), and those seeking to produce artworks with a sense of agency and autonomy. The autonomy present in some artworks inspired by biological systems has the potential of being experienced by visitors and creators alike as the systems having some kind of life of their own. This leads to a web of needs, whose interplay must be navigated in the creation of the work. There are needs common to most artistic practice: the artist's need for expression and fulfilment of aesthetic goals and the creation of work that can be parsed by visitors. However, as the creations edge ever closer towards creaturehood—or eventually, some form of personhood—additional needs arise. There may be a need to stay, in some sense 'true' to the creatures, to allow their narratives to develop alongside their implementation. When people experience digital algorithms associated with the physical structures of artificial creatures, there is a tendency to anthropomorphise, to project ideas of emotion and behaviour, and to empathise with them. Hence, there may also be a need to support the public's understanding of the piece in a manner which correlates with the experience of the creatures, to sculpt the anthropomorphisation to be consistent with the internal mechanics of the cyber entities.

2 Background and related work

In this paper we will discuss a particular project which the authors carried out, but it is important to connect this into a diverse collection of existing work.

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There is a vibrant history of swarm behaviour and artificial life within the world of computational art, many of which have influenced this project. To pick a few examples from many, Blackwell’s SwarmMusic [1] paired a digital swarm with a skilled human improviser to create musical duets; rAndom International’s *Audience* piece works with the idea of static robot swarm directing their attention to visitors which they find in some sense ‘interesting’³; Miranda created a series of digital societies where autonomous communicative agents developed repertoires of sounds [2]; finally, there is a clear relation to Ihnatowicz’s seminal *Sound Activated Mobile*⁴, one of the earliest cybernetic kinetic sculptures.

Part of our project engages with the relation between embodied algorithms and emotional responses, the ways in which we may socialise with robots [3]. Here, we are interested in the ways in which internal state is performed and understood, how activity is organised, and what gives rise to the underlying dynamics of action and response. In animal behavioural theory, we find the concept of modal action patterns—recognisable behaviours with clear preconditions underpinning theories of animal communication [4]. For instance, many animals have a zone around them, the transgression of which will provoke agonistic behaviour or a readiness to flee. For human psychology, Maslow’s hierarchy of needs [5] gives a common sense account of the underpinnings of human behaviour, based on the idea that human needs can be organised into a hierarchy, with each level of needs being dependent on the one below. There is hence the requirement to satisfy base needs before more rarefied desires are considered.

Analogies have been drawn between this hierarchy of needs and Brooks’ subsumption architecture for robotics [6]: multiple states exist with preconditions for activation, and the highest priority state which can activate at any point in time is given control of the robot’s actuators. This connection has not gone unnoticed, and forms the basis for several intelligent multi-agent systems e.g. [7, 8].

Another area of interest is the relation between digital creatures and their environment. Cybernetic organisms tend to have a different range of sensory and processing apparatus from humans, and this is reflected in their experience of their environment. Uexküll introduces the idea of *Umwelt*—the perceptual life-world which gives rise to the creatures’ biosemantic view of their environment: “Every subject spins out, like the spiders threads, its relations to certain qualities of things and weaves them into a solid web, which carries its existence” [9, p. 53]. The environments in which these creatures exist, however, are often created alongside their inhabitants, developed in dialogue with the ways in which the creatures practise and perform their behavioural routines. This creates a symbiotic relation, where the environment and its organisms shape and influence each other [10, p. 20], an ecosystemic network between the emerging lifeforms, their creators, and their visitors.

3 Description of the work

Lichtsuchende is an interactive installation, comprising a society of cybernetic creatures. The creatures base their interaction on the exchange of light, using it both as a source of energy and a means of communication. Visitors to the installation can interact with

³ <http://www.chrisoshea.org/audience>

⁴ <http://www.senster.com/ihnatowicz/SAM/sam.htm>



Fig. 1. Lichtsuchende installed in Vault 13 at Hidden Door Festival, Edinburgh, April 2014. Photo credit Chris Scott @chrisdonia

the creatures using torches to influence their behaviour (Figure 1). A video showing a pre-installation version of the robots can be found here: <http://bit.ly/1HF0od8>⁵.

The creatures resemble sunflowers to some extent: they are fixed to the floor, and rotate their heads to track light. They have a relatively curtailed set of basic capabilities for sensing and affecting their environment (Figure 2):

- Two actuators allow them to control the orientation of their head horizontally and vertically, covering most of a hemisphere. This both focuses their attention in a specific direction, and conveys a sense of focus.
- 5 isotropic ambient light sensors arranged in a cross allow them to sense the intensity of the light field in the direction of attention, along with gradients in intensity from top to bottom and left to right.
- A cluster of superbright LEDs emit a strong, narrow beam of light in the direction that they are facing, with variable intensity.
- Additional LEDs allow them to illuminate their stems as a means of conveying internal state.

This means their *Umwelt* is built on an extremely pared down set of basic inputs: they know which direction they are looking in, and they have access to a tiny slice of the structure of illumination surrounding them. A central aesthetic of this piece is to work outwards from this minimal set of capabilities to produce a rich and engaging experience.

⁵ The work has been shortlisted for an international art prize, details will be included in final submission

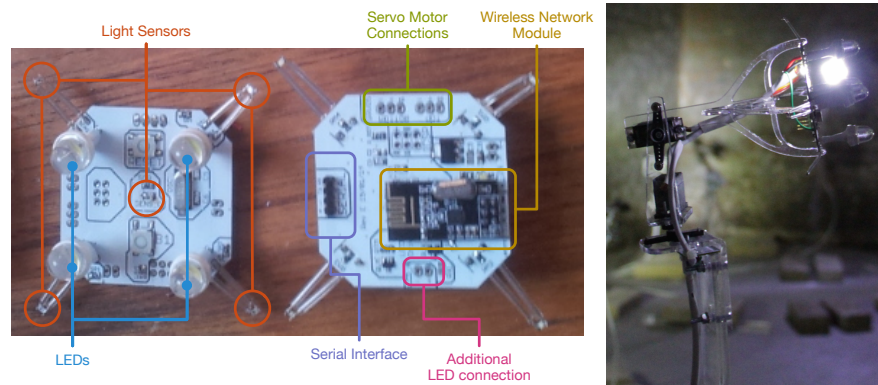


Fig. 2. Robot component detail showing a) the electronic components mounted on the main circuit board (note that the CPU is obscured by the wireless networking module) and b) the board mounted on an armature composed of transparent acrylic and servo motors.

The basic principle of action is the flowers' tendency to turn their attention towards sources of light, and to project light in the direction of their attention as a means of engaging. This connects their inner world to that of their fellows and any visitors in the installation environment.

We describe the piece along four axes: the thematic elements which inform its construction; the technical and material components which constitute the robotic creatures' physical presence; the implementation of the conceptual elements which give rise to the robot's behaviours; and the aesthetic and situational concerns relating to displaying the robots within an exhibition context.

3.1 Thematic motivations

As presented, the artwork draws on three broad themes, relating to the anthropomorphisation of embodied algorithms, the role of needs and desires in creating complex behaviour, and the emergence of socialisation both with a collection of robots and between robots and humans. In Section 3.4 we will unravel the emergence of some of these themes, but initially, we present them as a *fait accompli*.

Embodiment and interpretation One of the motivations behind this work is the relationship between simple specification and the perception of complex behaviour and state. This is especially apparent when the behaviours are embodied in a physical system that people can engage with. The key behaviour of the robots is tracking light by navigating the intensity gradient of the light field in front of them. This navigation is implemented as a purposefully crude and brutally simplistic algorithm, simply moving towards brighter light. However, the exigencies of the physical and digital incarnation of algorithms inevitably lead to idiosyncrasies, which are open to anthropomorphic interpretation. Slightly different algorithms and parameterisations give rise to patterns of movement which can be interpreted as curious, nervous, excitable, graceful and so on.

Some physical behaviour is unplanned, resulting from their embodiment and situation: if a person reaches out to touch a flower which is tracking light, their hand casts a shadow on the sensor, and the robot will turn away. This can happen abruptly, and has been interpreted as shyness, or a nervous reaction. We are interested in the reactions which these algorithms provoke, and which responses are due to intentional design parameters versus idiosyncrasies of implementation.

Navigating internal state Ihnatowicz’s cybernetic ‘Senster’ has a single behaviour—to track continuous sounds. There is a lot of nuance within this behaviour, such as the ways in which different sounds trigger movement, but ultimately it is a direct, immediate response to input. In order to enrich the possibilities for action, we draw on: i) Maslow’s hierarchy for an organisation of internal states; ii) Brooks’ subsumption architecture for a computational implementation of these states; and iii) Barlow’s modal action patterns as a means to enact and display these states (see Figure 3). The states derived correspond to physical and emotional concepts, a sense of desires, and the means to satisfy them. We are interested firstly in how the robots’ internal state can be communicated to visitors, the relation between display and interpretation and matching conceptual ideas to anthropomorphic readings. Secondly, how can the network of states be constructed to give rise to pathways of behaviour that are understandable and plausible in the context of creaturehood.

Emergent behaviour, interactivity and socialisation The behaviours above provide a link between the individual and the social, and these interrelationships provide fertile ground for emergent behaviour. At one level, there are the effects of having several autonomous, embodied entities sharing a space: communication may occur or not; if it does, it may be subject to misinterpretation, or interrupted by the actions of others. There is the possibility of cascades of behaviour change throughout the space, a positive feedback as each robot activates others, spreading excitation. The system may become stuck in one overall global state, such as all of the robots deactivated and unable to initiate movement. There may be local patterns, where some of the robots become locked into enmeshed repetitive behaviours. We are interested in the question of what it takes to design an ‘interesting’ robot society, which exhibits a range of behaviour, which reacts to visitors but has its own internal dynamics, and which doesn’t exhibit pathological complete failure modes.

3.2 Internal states and their implementation

As previously noted, the central characteristic of the creatures is their fascination with light, their immediate enrapturement and constant alignment with any source of photons. However, this is only one of their possible behavioural states (Figure 3), which are arranged in a rough parallel with Maslow’s hierarchy of needs [5]. The basis for moving between the behaviours is the sensory input available to the creature, combined with internal variables to representing energy level, the time spent tracking a source and so on. Taken in increasing priority, the states, their conditions and the associated observable activities are as follows:

Sleeping occurs when a flower lacks energy. The head is pointed downwards, and the base pulses slowly with light, intended to evoke the calm breathing of a sleeping animal. While the flower sleeps, its energy level gradually increments.

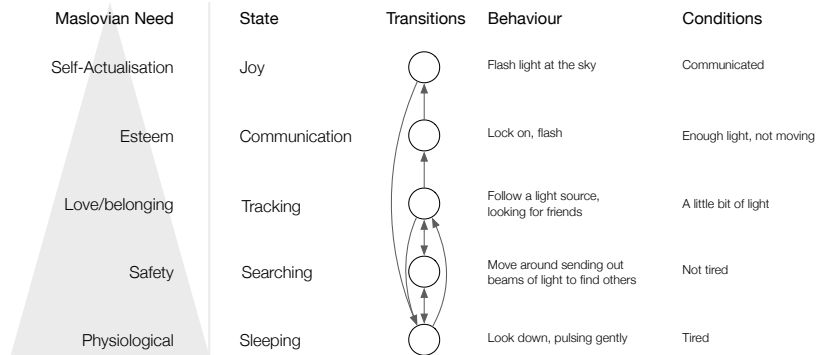


Fig. 3. Behavioural states of the robots with their activation conditions, and a relation to the Maslovian hierarchy of needs.

Searching occurs when a flower has some energy, but there is no strong light source present. It will move by a small, random amount, and then send out a slow pulse of light in that direction to see if anything responds. This enables the flowers to maintain their society in the absence of any human intervention.

Tracking is the response to any sufficiently bright light source. The flower will turn towards the sensor(s) giving the highest reading. This is a simple, cybernetically inspired approach, with differences in intensity between opposed sensors driving acceleration in each axis ⁶. When tracking, the robot outputs a strong beam of light, to allow itself to be tracked by whatever is producing the light. Tracking consumes a lot of energy, meaning that often the flower will go to sleep if the light source is lost.

Communication is enabled when a robot has seen a bright light, for a certain amount of time, with minimal movement. This indicates that it has enough evidence that the light source is a fellow flower, and discourse can begin. The physical effect is that the robot freezes in place, and flashes rapidly, as a placeholder for exchange of information.

Joy occurs when communication is successfully completed: the flower points at the sky, emits a few bright flashes of light. It then points down towards the ground with the base pulsing rapidly to indicate brief exhaustion, from which it cannot be interrupted. At the end of this behaviour, the flower goes back to sleep.

3.3 Aesthetic and interactive considerations

In addition to the ideas of state, action and behaviour outlined above, since the endeavour was to create an interactive art installation, we had some aesthetic principles to guide construction and deployment of the robots:

- The work should be immediately accessible, and give a broad range of visitors a direct way to engage, yet rich enough to support some degree of prolonged investigation.

⁶ Roughly: $d\theta_{lr}/dt \sim i_l - i_r$ where θ_{lr} is the pan or horizontal alignment of the head, and i_l and i_r are the intensities of the left and right sensors respectively, with a similar relation holding for the vertical (tilt) orientation. However, tweaks have been made to stabilise this in an effort to improve the interactivity.

- Nothing should be hidden: all of the electronics, cables, motors, circuits and sensors are clearly visible. There are no coverings or casings to hide the skeleton and nervous system of the creatures. The only parts which are hidden are the egregiously ugly computer power supplies used.
- The work should be minimal, so colour has been avoided, using only black, white and transparent materials. No additional sound has been added, leaving just the susurrus of 60 servo motors to create the sonic environment.
- The creatures should be part of the space in which they are situated. This generally means finding spaces with character in which to show them, and finding some kind of locally relevant material to connect the plastic and electronic entities with their surroundings.

3.4 An account of the emergence of embodied identity

The account given so far presents a certain picture of the piece, in a relatively resolved, finished form. Of course, as with any project, the realities of development are far messier and more complex than the polished presentation given above. In many pieces of work, this developmental process would be taken as a given: ideas are refined as they are tried and executed, design becomes iterative as it meets reality. However, this piece involves robots which are working their way towards creaturehood. As such, development needs to take into account several different communities, their reasons for being part of the process. As usual, we must consider the web of relations between the artists and creators of the work, and the audience of the work, but here we must also consider the community of creatures which form the body of the work: what are their needs, their reasons for enrolling in the cyber-society and initiating dialogue with the visitors. There is a parallel here to Callon's seminal work on translation in Actor Network Theory, where the organisms under scrutiny—scallops—are taken as actors within the system [11]. The development of the piece must balance the emerging identity of the digital creatures against the artist's original intention and the presentational necessities related to exhibiting art for an audience.

In order to engage with this, we present a shared account, teasing apart how the conceptual development was informed by the coalescence of the infant creatures' character.

Initial Experiments The initial seed of development had nothing to do with artificial life, or biologically inspired robotics. The germ of the project was a pure electronics experiment: we wanted to construct a very simple mechanism which moved a servo motor from side to side in response to changes in light. This was an undirected act of construction: at this point, we had no strong idea of a piece in mind, or conceptual framework for constructing one. Using scrap circuit boards, glue and toothpicks, we put together a slightly enhanced version of the original idea which used four sensors and two servos to track bright lights. A video of this setup can be found here: <http://bit.ly/1vkdMy6>. As soon as we played with this, the potential for anthropomorphisation was apparent: the movements seemed eager, straining. Overshoot and positive feedback gave it a bit of a twitch, a nervous tick. Suddenly, it felt alive, and the idea formed to use this as the basis for creating a society of creatures.

Reactions to embodiment Based on this, we set out to construct several robots, and look at their potential for interaction. To do this, the robots needed to produce

light, so we added LEDs, and created three prototypes. A video of this can be found here: <http://bit.ly/1rq758A>. As Anderson said, “More is different” [12]: the interrelationships and structures which emerged from having several robots interacting fundamentally changed the way in which we viewed them. They transitioned from being assemblages of components to—approximately, metaphorically—living beings. There were several specific events which brought this about:

- As previously noted we found that reaching out to touch one of the robots often makes it jerk away. Intellectually, this is just a reaction to the shadow cast by a hand; however, this was clearly interpretable as shyness, retreating from unfamiliar touch. This was not a behaviour we had planned or anticipated, yet it felt very much in line with the character we were starting to imagine.
- When two robots came face to face when they are very close together, they begin jerking around wildly—this can be seen at 00:58 in the video above. As their creators, we knew that this is simply an artefact of the implementation: quantized time and position representations coupled with a crude algorithm lead to overshoot, positive feedback and instability. However, it was difficult to shake our gut reaction, that this was a communication, a territorial display, a reaction to the invasion of their space.
- One of the prototypes—now proto-creatures—lost a sensor. This threw out its tracking algorithm, and it ended up systematically smashing itself to pieces on the post next to it. This was surprisingly distressing to watch, conjuring images of mental illness and self harm. Again, it was hard, on a personal level, to separate knowledge of the algorithmic causes from our emotional response to the enacted movements.

Taken together, the existence of unplanned behaviour, the emergence of needs and communication and the potential for pathological behaviour made it impossible to ignore the growing identity, autonomy and socialisation of these creatures.

Inner lives The next point of engagement was to try and add some variation to the behaviour: it felt incomplete that the creatures would only ever reactively track light, without purpose, boredom or communication; there needed to be some teleological context for that behaviour. We started to think about what existence was like for these robots, what would motivate their movements and actions, and how their limited *umwelt* could be parsed into states which we consistent with both their life narratives and our interpretations of what they were doing. It was at this point that we invoked the mechanics of Brooks’ subsumption architecture coupled with Maslow’s hierarchy as a way to develop the psychology of the individuals.

The final set of states are given in Section 3.2, but this doesn’t relate to their development. It is one thing to have a clear conceptual idea of what the creator would like the states to be, and another to implement them in a digital creature. We had to experiment with different ideas, abandoning some—such as transmitting serial bitstrings by flashing their lights—due to time constraints or technical difficulties, and others as they did not ring true with the emerging character of the robots.

A large part of the process was developing the biosemiotics relating to the different states and their human interpretation. We can say that there is a behaviour called ‘sleeping’, but that requires definition in terms of both sensor outputs and state variables, and the code which comprises the active behaviour. This is a process of translation, of ideas into code (Figure 4); the translation involves parameterisation, which is often a poorly constrained process in these situations. It is also a process of alignment with

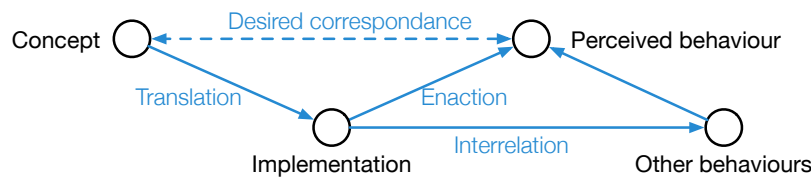


Fig. 4. Relationships between ideas, implementation and perception for the behavioural states of the robots

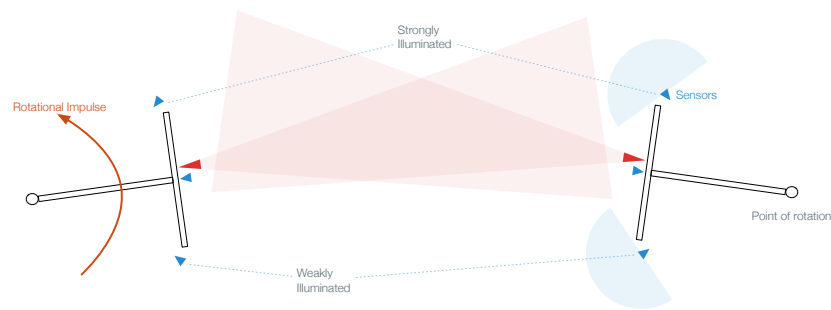


Fig. 5. Illustration of the way in which the robots experience and react to slightly off-axis alignment with others. For both robots, the brightest part of the beam intersects with the topmost sensor, so the intensity gradient increases towards the top of the diagram, giving a rotational impulse *away* from alignment rather than towards.

perception, correlating the performance of behaviours with human interpretation. Initial versions of the way in which ‘sleeping’ was performed presented as either too sparse, feeling more like malfunction or coma, or too active, losing their tranquil, reflective aspect. Similarly, the transitions needed management: a robot going to sleep in the middle of an interaction with a human can leave them disappointed or frustrated.

There were conflicts here which needed to be resolved between our intentions as artists, and what came naturally to the flowers, avoiding doing violence to their autonomy. This is in contrast to other projects we have carried out, where there is some phenomenon or concept we wish to articulate using technological means, and development is fundamentally about making that elucidation as clear as possible. Here, we had to work within the needs and idiosyncrasies of the community we were creating, and acknowledge the gulf between clean conceptual ideas and their implementation in a messy, limited sphere.

Come find me - search and reaction Once a reasonable set of behaviours were in place, we could concentrate our effort on one of the core ideas, that of the flowers managing to connect with each other and transmit information. Conceptually, this felt like it should be straightforward: as a human with a torch it was intuitive and easy to make a flower point in any direction, so they should be able to find each other.

However, this showed up the differences between our *umwelt* and that of the flowers. We are situated in three dimensional space, with powerful sensory apparatuses, and can resolve the position of distant objects. The robots sensors are isotropic across a half sphere, so they do not resolve the source of light—they are only sensitive to how the beam intersects their sensors, not its origin (Figure 5).

In order to understand this issue, we needed to imagine what it is like to be one of the robots [13], to try to internalise their nascent biosemantics. It became clear that there was not a clean, implementable analytic solution to the problem of two robots aligning themselves, and that some form of memory and negotiation was needed. In response, we built a modified, collaborative version of a simplex search [14] into the robots. If one thought it might be near to connecting with something, it would sweep out a cross pattern, recording light intensity. Depending on the maximum value, it would adjust the cross to grow or shrink in either dimension⁷. It would then freeze in the centre of its cross for a random amount of time, and emit light in proportion to how much it was receiving. This allowed the objective function to be based on how much light was reaching the *other* robot, using collaboration to make up for limitations in the sensory apparatus, and pairs of flowers would gradually converge on each other’s locations.

However, this caused a disconnect: the flowers could now find each other relatively well, but the motion they used to do so was inaccessible to humans. While it was visually reminiscent of mating dances and other codified animal behaviour, it was an abrupt difference to the smooth tracking motion, and more importantly, it was an activity which humans could not participate in due to their different capabilities. In the interests of interactivity, we settled for tweaking the existing behaviours, modifying the tracking algorithm to move less if it is close to a connection, and to allow the robots to be more promiscuous with their connections.

Presentation and aesthetics At this point the identities of the robots were well resolved: they could sometimes connect with each other, and had autonomous lives and interactions with or without human presence. In order to make a compelling installation, we then needed to adjust the parameterisation and setup of the robots to create the right feeling. In early tests, there was a lot of activity, fast movement and flashing, which felt at odds with the way the creatures wanted to be: it was a byproduct of moving from exploring with a group of two or three to suddenly having a larger society. In response, we looked for ways to balance out their activity, letting them sleep for longer, move more slowly and pulse more gently. Given the time demands, we did this by adjusting parameter settings; a more sensitive technique would be to give the robots control of their own activity levels, so they could respond to a changing societal context.

In the end, we found a range of interactions between the robots, some of which were intentional, some which were emergent, and most of which were accessible to people we tested them with. This included:

Wake up: the beam of one flower grazes the sensors of another and wakes it up, but the connection is lost before anything further can develop.

Brushing: one flower grazes another, and there is a weak connection, where their movements align briefly, a small moment of choreography, which then dissipates.

⁷ The modification to the general simplex algorithm is largely to cover the idea that moving to a new point to sample it is expensive, while actually evaluating the objective function is cheap.

Negotiating: two flowers find each other and interact for a period of time, circling around alignment. However, they are not able to settle, lock and satisfy each other, and their attention is taken either down into sleep, or out to another source of light.

Connecting: two flowers find each other and start negotiating, then go further and actually manage to settle and lock with one another, flashing sequences of light at each other.

Repetition: a group of flowers become enmeshed in a cycle of incomplete connections, passing animus back and forth, with one missed connection brushing another flower into life. Conversational groupings emerge, with similar motions and negotiation, and occasional moments of connection.

This range felt appropriate: there was richness, and emergence, but an observer could parse the choreography, make sense of the links, and interfere at will.

3.5 Actors and networks

It would be helpful in this situation to have a framework for looking at the competing demands of the various entities engaged in this process. Minimally, this means the robots, their creators and any visitors, but this can extend to the gallery and funding agencies which permit the creation and exhibition of the work.

Latour included non-human actors within Actor Network Theory, starting with the anthrax bacterium [15]. This allowed an analysis of the power relationships between various people and the bacterium. This is also evident in Callon's analysis of the networks between scientists, fishermen and the scallops which they fish. As well as giving a framework for considering the different needs and characteristics of the actor groups, this view looks at *interessement*, the means by which the various actors are enrolled to perform within the network: "... physical violence (against the predators), seduction, transaction, consent without discussion." [11]. Within this setup, we find several devices of *interessement*.

Multiple aspects of the space and context conspire in the *interessement* of the robots. Their consent to be present is assumed without discussion, as they are disassembled, shipped and re-assembled in situ. By their positioning, they are seduced into engaging with others, fulfilling their societal roles, and by the addition of torches they can be seduced into interacting with human visitors. Physical structures are used to keep the visitors from damaging the flowers, maintaining the flowers' survival, their ability to act and to enroll in their society.

Similarly, the architecture of gallery and exhibition spaces is set up to enroll people to perform as visitors. In this, additionally, having a curtain to pass through and a disconnected space further lock visitors into their roles. The picking up and using of a torch further *interesses* visitors into the cyber-society, setting up the context for their interaction with the robots.

Finally at all points, there is the negotiation around: does power move towards the creators, altering the creatures without consent towards an imagined ideal? does power move towards the visitors, subjugating the behaviour and conceptual underpinnings of the creatures to provide an engaging or entertaining experience? or does power flow towards the creatures, pushing their creators and visitors to align themselves with the creatures modes of being?

4 Conclusion

In this paper, we have looked at the development of a biologically inspired robot swarm. We have taken a viewpoint which touches on:

- The gulf between clean, presentable specifications of desired behaviour and the implementations which allow a rich, emergent set of responses.
- How the biosemantics of the lifeforms under development may be non-intuitive, and hence the need for a translational imagining of their experience as part of their development.
- The need, when creating artificial life, to carry out a continual negotiation between the needs of the nascent lifeforms, their creators and imagined or actual visitors. In particular, the manner in which the creators engage in a duet with creatures which do not yet exist, in order to allow their identity to emerge.

As a potential framework for dealing with these tensions, we have sketched some of the components of an Actor Network Theory approach to analysing the situation, which provides insight into the devices used to engage people and robots in the interactions, and a model for understanding their competing needs.

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